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COLORIMETRIC IDENTIFICATION OF PORCELAIN BY MATERIAL TYPE

Yu. T. Platov,[1] R. A. Platova,[2] and D. A. Sorokin[1]

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Colorimetric identification of porcelain articles by material type is reduced to finding the classification functions which are obtained on a training sample and relate the color coordinates with the form of porcelain according to the material type. These functions must be regarded as a statistical model for determining whether or not new porcelain samples belong to one of the porcelain types according to the material.

Key words: porcelain types, color distinguishment, cluster analysis, discriminant analysis, statistical model, colorimetric identification

The draft of the Federal law (special technical regulations) "On the safety of ceramic dinnerware" divides the quality indices for such articles into two groups which characterize the safety and identification of dinnerware by material type. Color is used in two ways to identify ceramic articles: first place, color is a subjective criterion for organoleptic evaluation for determining the type of ceramic materials and, second, an instrumentation method is used to evaluate the whiteness of porcelain.

It is shown in [1] that whiteness according to GOST 24768 cannot serve as a criterion for distinguishing porcelain by color into hard and bone porcelain and that the color indicators in the 1976 MKO $L^*A^*B^*$ colorimetric system provide a more accurate color assessment tool than a verbal description of the color representations in an organoleptic evaluation of porcelain dinnerware by material type. For this reason, it can be supposed that if experts making an organoleptic assessment of samples of hard and bone porcelain predominately according to the color and transmission of samples of hard and bone porcelain distinguish them completely accurately, then there probably exists a colorimetric system of indicators which can be used to make the same color discrimination objectively.

The objective of the present work is to construct an expert system for distinguishing the color of samples of white porcelain by material type.

The colorimetric identification of porcelain by material type requires solving two problems:

a database consisting of a description of the objects and their indicators characterizing the color region of hard and bone porcelain must be constructed;

an expert system must be constructed in the form of a system of statistical functions on the basis of which a "response will be synthesized" to the unknown color coordinates and a decision will be made to classify a sample as a particular type of porcelain by material type.

Construction of the Database. The problem of constructing a database can be formulated as follows. Let there be a training sample of objects which consists of N samples of porcelain for each of which the reflection spectrum is measured and the appropriate equations are used to calculate the color coordinates in the 1976 MKO $L^*A^*B^*$ colorimetric system. The database can be represented in the form of a matrix

$$X = \| X_{ij} \|,$$

where $i = 1, M$ ($M = 3$ is the number of color coordinates L^*, A^*, B^*) and $j = 1, N$ ($N = 94$ is the number of porcelain samples).

The rows of the matrix correspond to the porcelain samples and the columns to the color coordinates.

Ninety four samples of porcelain articles distinguished by material into bone and hard porcelain and by country of origin (Russian, Japan, England, Germany, China, and so on) were used for these investigations.

The porcelain samples possess a flat surface larger greater than 20 mm, which corresponds to the size of the aperture of the "Pul'sar" spectrophotometer. The measurements

[1] G. V. Plekhanov Russian Economics Academy, Moscow, Russia.
[2] Russian State Trade and Economics University, Moscow, Russia.

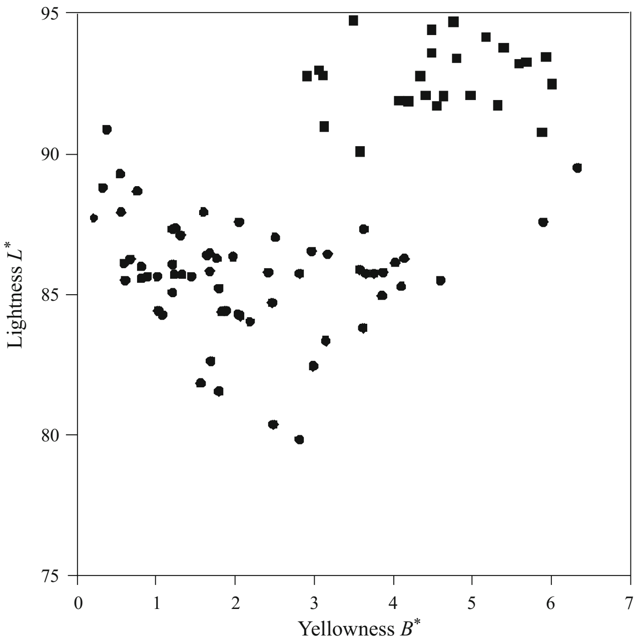

Fig. 1. Position of the porcelain sample in the lightness L^* – yellowness B^* coordinate plane of the MKO $L^*A^*B^*$ colorimetric space: ●) hard porcelain samples; ■) bone porcelain samples.

of the reflection spectrum of the porcelain were performed in the wavelength range 380 – 720 nm in a $d/8$ measurement geometry with a C illumination source C and 1931 MKO colorimetric observer position equal to 2°, neglecting the mirror component. The "Foton" software is used to control the measurement process and perform the calculations of the colorimetric parameters.

The ranges of the color coordinates L^*, A^*, B^* and of the yellowness G (ASTM D 1925) as well as whiteness W_{ISO} of hard and bone porcelain [1] are presented in Table 1, and the position of the porcelain samples in the coordinate plane lightness L^* – yellowness B^* is displayed in Fig. 1.

Thus, a database which includes a set of porcelain samples and characterizes the color region of hard and bone porcelain has been constructed. A priori information on the porcelain samples makes it possible to divide them by material type into two non-overlapping groups in the MKO $L^*A^*B^*$ color coordinate plane.

Distinguishing porcelain samples by color in the MKO $L^*A^*B^*$ coordinate system means creating a dictionary of indicators $i = 1, M$ ($M = 3$) that makes it possible to associate the same sample to one of the porcelain groups by material. However, such a dictionary of indicators is insufficient for identifying porcelain samples by material.

Construction of an Expert System. Colorimetric identification of porcelain samples by material is understood to mean dividing a set of samples into groups S (classification procedure) together with a procedure for making a decision as to whether or not new samples belong to one of the groups by material. The criteria for determining whether or not the color of a sample belongs to a type of porcelain according to the material are determined by a decision rule which can be a classification function. The deciding rule is constructed using two systems: "without training" (cluster analysis) and "with training" (discriminant analysis) [2].

The classification of porcelain samples according to the colorimetric characteristics is based on three procedures: performing measurements, choosing an algorithm for cluster analysis, and evaluating the quality of the classification.

A measurement is taken to mean scaling together with a method for determining the closeness of objects [2], while the process of performing a measurement of a property is understood to mean assigning numerical values to individual levels of the indicators of this property in definite units. The main scale types used for measuring the value of a property indicator are divided into qualitative (name, nominal, ordinal, and so forth) and quantitative (interval and relative). In our case two types of scales are used for the characteristics of color distinguishment of porcelain samples by material:

qualitative — name scale (hard and bone porcelain);

quantitative — relative scale (color coordinates in the MKO $L^*A^*B^*$ system).

A measure of the distance (measure of dissimilarity) between objects is used to evaluate the distance between objects in cluster analysis. Two objects are identical if the variables describing them assume identical values. Two of the best known measures of distance are Euclidean and Manhattanean ("city block") [3].

Measurement of the closeness of objects in terms of the Euclidean distance is a popular metric [3]. Geometrically, it does the best job of combining objects into spherical clusters, which are typical for weakly correlated collections of objects. For example, the Euclidean distance is used in colorimetry to measure the color distinguishment $\Delta E(L^*, A^*, B^*)$ between objects in the MKO $L^*A^*B^*$ colorimetric space [4].

Choice of Algorithm for Cluster Analysis. The procedure used in cluster analysis consists in finding groups of similar objects in a data sample according to a set of indicators. These groups are called clusters [3]. Hierarchical

TABLE 1.

Porcelain type	Color coordinates			G, %	W_{ISO}
	L^*	A^*	B^*		
Hard	77.0 ... 90.9	– 2.9 ... 1.7	0.2 ... 6.8	0.1 ... 13.7	26.9 ... 76.4
Bone	91.9 ... 94.7	– 1.6 ... – 0.3	4.1 ... 6.0	7.0 ... 10.5	49.6 ... 69.3

agglomerative algorithms have been chosen from among many cluster methods; they actually differ only by the method used to calculate distances between clusters.

The previously presented matrix of data, which were processed using the most widely known methods — distant and close neighbors, weighted and unweighted average correlation (using the Euclidean and “city-block” distance measures) — was used to group porcelain samples together according to the colorimetric characteristics.

The porcelain samples are divided according to the colorimetric characteristics into 3 – 6 clusters, depending on the cluster-analysis algorithm and the distance measure.

The porcelain samples are combined by material into different clusters: samples of bone porcelain are placed into one cluster and samples of hard porcelain are placed into two clusters. It should be noted that two samples of hard porcelain (19 and 47) always form a separate cluster irrespective of the method used, while the samples 1 and 14 form, as a rule, outliers with samples of bone porcelain.

The presence of outliers in clusterization is an important factor that affects the quality of the classification. Cluster analysis solves well the problem of identifying outliers. The presence of a few clusters whose average levels differ sharply from other clusters, with respect to at least one indicator, attests to the anomalousness of these objects. The coloristic characteristics of samples which have a substantial jump with respect to the distance of identification with the two main clusters are presented in Table 2. The following porcelain samples belong to them: 28 — high redness and visual assessment shows a light-rose hue; 19 and 47 — high yellowness with very low lightness; 1 — high yellowness and lightness; 14 and 21 — very high yellowness. With respect to the whiteness W_{ISO} and yellowness G these samples occupy extreme positions on the corresponding scales.

Thus, three clusters which are the so-called alphabet of porcelain classes with respect to color coordinates have been identified. The first cluster incorporates samples of hard porcelain, the second one samples of bone porcelain, and the third one hard porcelain with whiteness $W_{ISO} < 40$, which according to the GOST R ISO 105-J02–99 gradations is not a white color.

Evaluation of Classification Quality. An important step in the colorimetric identification of porcelain by material is making a decision concerning the number of porcelain groups on the basis of cluster analysis. Porcelain is divided into two groups by material — hard and bone. At least three clusters are formed with clusterization of a set of porcelain samples according to the color coordinates. In this connection we use two strategies to make a decision:

singling out two groups differing by material: hard and bone porcelain (1 and 2, respectively);

singling out three groups: two are similar to the first solution and the third one incorporates samples of hard porcelain whose color cannot be considered as white.

The quality of the decisive rule for classifying porcelain by material using colorimetric characteristics was checked using the same training sample by the method of discriminant analysis [5].

TABLE 2.

Hard porcelain sample	Color coordinates L^*	A^*	B^*	G, %	W_{ISO}
47	78.8	– 0.77	5.48	11.7	29.6
19	76.9	– 1.03	4.03	8.5	29.3
28	87.9	1.64	0.56	0.1	73.1
21	83.3	– 0.94	6.75	13.4	27.8
14	87.5	– 1.19	5.90	11.3	41.8
1	89.5	– 0.72	6.41	12.3	43.8

At this stage we add to the data matrix an additional indicator that designates the number of the group (qualitative scale), i.e., an indicator that takes on the values 1 and 2 and corresponds to the porcelain material (first strategy) or the values 1, 2, and 3 where the third number identifies a group of samples of hard porcelain by whiteness (second strategy).

It was determined that when the porcelain samples are classified according to the coloristic characteristics using two decision-making strategies the classification made by the second strategy is of higher quality than that made using the first strategy. Consequently, we choose the second decision-making strategy for the subsequent analysis.

The reliability of the deciding rule is quite high, and the null statistical hypothesis of the color indistinguishability of porcelain samples by material must be rejected. The statistical significance and discriminating power of the main functions were determined by measuring the residual discrimination using Wilks and F statistics.

The values of the F statistic $(6, 178, 0.01) = 45.3 > F_{table} = 2.90$ for the differences between groups and F-exclusion statistic for each color coordinate were analyzed. The former characterizes the quality of the separation into groups and latter the contribution to the distinguishment attained by means of the color coordinates. The difference between groups is significant with probability $P = 99\%$, and the lightness coordinate L^* ($F_{elim}(2, 89, 0.01) = 123.8 > F_{table} = 4.82$) and yellowness coordinate B^* ($F_{elim}(2, 89, 0.01) = 19.0 > F_{table} = 4.82$) with negligible redness contribution make the greatest contribution to the color distinguishment of porcelain by material.

The maximum number of discriminant functions is 2 (number of groups minus 1). The characteristic values of the first and second functions, equal to 4.40 (96% fraction) and 0.18 (4% fraction), are related with the discrimination possibilities of these functions: the greater the characteristic value, the better their color distinguishment is. Consequently, the first function gives the greatest and the second a less significant color distinguishment.

According to the values of standardized coefficients of the first and second discriminant functions (DFs), the greatest color distinguishment according to the first DF comprises

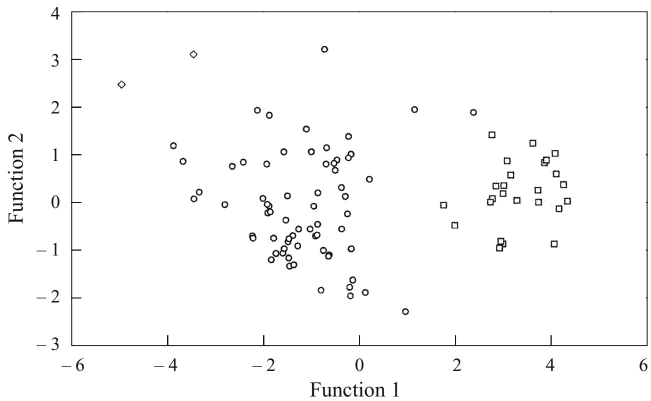

Fig. 2. Arrangement of the samples of hard and bone porcelain in the coordinate plane for two discriminant functions: ○) group 1 (samples of bone porcelain); □) group 2 (samples of hard porcelain); ◇) group 3 (samples of hard porcelain with $W_{ISO} < 40$).

lightness $f(L^*) = 0.98$ together with yellowness $f(B^*) = 0.90$, whose values are inverse to the lightness $f(L^*) = -0.32$. If the samples of bone porcelain (first group) are negligibly dispersed relative to the first and second DFs, then the samples of hard porcelain (second group) are dispersed non-negligibly (Fig. 2); this is explained by the large range of variation of the values of the lightness L^* (from 80.0 to 89.5) and yellowness B^* (from 0.5 to 6.0) of hard porcelain.

So, discriminant analysis permits formulating an informative hypothesis on the color distinguishment of samples of hard and bone porcelain.

The visualization of the data by projecting objects — porcelain samples — into the space of two discriminant axes is represented in Fig. 2. The set of porcelain objects is represented as a cluster of points in several regions of the experimental space. The regions of the three groups do not overlap in this space, since there is a significant color distinction between them.

Classification is a process which a decision-making aid: an indicated sample “belongs to” or “is very similar to” a particular group of porcelain samples distinguished by material. Such a decision is made on the basis of information contained in the classification functions.

A classification function has the following form:

$$h_k = b_{k0} + b_{k1} L_j^* + b_{k2} A_j^* + b_{k3} B_j^*,$$

where h_k are the values of the function for class k ($k = 1, 2, 3$); b_{k0} is a constant; b_{k1}, b_{k2}, and b_{k3} are coefficients (their values are presented in Table 3); L_j^*, A_j^*, and B_j^* are color indicators of the sample ($j = 1, ..., N$).

Classification functions (see Table 3) can be used to predict whether or not a new sample belongs to one of the

TABLE 3.

Coefficient	Classification function		
	1st	2nd	3rd
b_{k1}	25.82	28.10	23.78
b_{k2}	13.54	14.02	13.10
b_{k3}	7.43	9.18	8.23
b_{k0} (constant)	– 1103.84	– 1312.71	– 943.45

groups. Applying these three classification functions to the new primary data we can obtain three values of h_k. In this case the sample belongs to a group with the maximum value of h_k.

In this way the identification of porcelain articles by material type reduces to finding the classification functions obtained on a training sample and relating the color coordinates with the type of porcelains by material. These functions should be regarded as a statistical model for determining whether or not new samples of porcelain belong to one of the types of porcelain by material.

Having solved all these problems, the construction of an expert system for identifying porcelain articles by material using a colorimetric method is complete. Indeed, there exists a database that includes a set of porcelain samples and characterizes the color region of hard and bone porcelain. A priori information on the porcelain samples permits dividing them into non-overlapping groups in the plane of the 1976 MKO $L^*A^*B^*$ color coordinates. This defines a dictionary of indicators for describing each group of samples and constructing identification algorithms, which compare the a posteriori data on the porcelain samples with the a priori information; the result of this comparison is the determination of whether or not porcelain samples belong to one of the types by material.

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